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Growth and Development of Irrigated Sunflower in the Texas High Plains

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ABSTRACT

Sunflower (*Helianthus annuus* L.) is widely adapted in the USA. In the southern Great Plains, it has been planted from March to August, but time of planting affected its growth, yield, and quality. Objectives of this study, conducted on Pullman clay loam (Torrertic Paleustolls), were to determine the effect of planting dates and associated environmental factors on sunflower growth, development, yield, quality, and water use. A better understanding of these effects could lead to improved management of this crop. The sunflower was planted from late March to late July in 1980 and 1981. For each planting, sunflower growth, development, yield, and quality were determined and related to environmental factors by simple correlation and multiple regression analyses. Sunflower planted from early April to early June yielded more than earlier- or later-planted sunflower. Values for most other sunflower variables either increased or decreased progressively from the first to the last planting. Early planted sunflower developed slower and used more water than later-planted sunflower. Planting after early June also resulted in low water use efficiencies because of lower yields. Consequently, early and late plantings are not recommended because they resulted in lower water use efficiency than sunflower planted from April to early June. Oil concentration of seed decreased with later plantings, which resulted in lower total oil production. Based on this study, sunflower in the Texas High Plains should be planted from about mid-April to early June to use water efficiently and to obtain favorable yields of seed having a high oil concentration.

***Additional index words:* *Helianthus annuus* L., Soil temperature, Air temperature, Solar radiation, Daylength, Daylight, Linoleic acid, Oleic acid, Water use, Water use efficiency.**

SUNFLOWER (*Helianthus annuus* L.) is an important oilseed crop in the USA. Most of it is grown in North Dakota and surrounding states, but it has a wide range of adaptation. In the southern Great Plains, which includes the Texas High Plains and surrounding areas, sunflower has been planted from late March until early August. Yields declined sharply for sunflower planted after about 21 June; those planted on 15 May or later had significantly lower seed oil concentration and significantly higher linoleic and lower oleic acid concentrations of the oil than those planted before that date (Unger, 1980).

Temperature has been shown to influence sunflower seed yield and quality. Yields generally were highest when seed developed during periods of moderate temperature (Anderson et al., 1978; Johnson and Jellum, 1972; Murphy, 1978; Unger, 1980) and lower when development occurred during periods of relatively high temperatures (Bhattacharya et al., 1975; Downes, 1974; Keefer et al., 1976) or low temperatures (Anderson et al., 1978; Johnson and Jellum, 1972; Keefer et al., 1976; Murphy, 1978; Unger, 1980). Seed yields were influenced also by temperature during vegetative growth stages (Anderson et al., 1978), by solar radiation (Anderson et al., 1978; Keefer et al., 1976), and by daylength (Keefer et al., 1976).

Reported temperature effects on seed oil concentration have been variable. Higher oil concentrations at high than at low temperatures were reported by Johnson and Jellum (1972), Jones (1984), Robinson (1970), Unger (1980), and Unger and Thompson (1982). Downes (1974) and Harris et al. (1978) reported opposite results. Canvin (1965) showed that oil concentration was not affected by temperature and Anderson et al. (1978) found no correlation between oil concentration and planting time, which implied that temperature had no effect. Anderson et al. (1978) suggested, however, that oil concentration is controlled by a complex set of factors including temperature during seed development.

Positive and negative correlations of oleic and linoleic acid concentrations of oil, respectively, with temperature during seed development have been frequently reported (Anderson et al., 1978; Grindley, 1952; Harris et al., 1978; Johnson and Jellum, 1972; Jones, 1984; Keefer et al., 1976; Unger, 1980). However, Unger and Thompson (1982), using multiple regression techniques, established that oleic and linoleic acid concentrations of oil were significantly related to solar radiation and daylength, but not to temperature, during seed development. Radiation and daylength could have been factors in the different linoleic and oleic acid concentrations reported by Filipescu and Stoenescu (1978) for sunflower grown at a wide range of latitudes, although they considered temperature as the major factor.

Early planted sunflower generally yielded more seed that had a higher total oil concentration than later-planted sunflower in the southern Great Plains (Jones, 1984; Unger, 1980). However, oil from later-planted sunflower had a higher concentration of linoleic acid, which is desirable for salad oils and margarines (Robertson et al., 1979). To obtain favorable seed yields and concentrations of linoleic acid, a compromise planting date seems desirable. The decision regarding when to plant should be based on a thorough understanding of the environmental factors that influence sunflower growth, development, yield, and quality. Such understanding could also lead to improved management of this crop with respect to irrigation, tillage, and residue management practices, which could be used to alter the microenvironment where the crop is grown. The objective of this study was to determine the influence of planting date on irrigated sunflower growth, development, yield, quality, and total water use. Use of different planting dates caused germination, growth, budding, flowering, and seed development to occur during periods of widely different temperatures (soil and air), radiation, and daylength.

MATERIALS AND METHODS

The field study was conducted on Pullman clay loam (fine, mixed, thermic Torrertic Paleustolls) in 1980 and 1981 at Bushland, TX, which is at 35°11′N102°5′W. Elevation is 1180 m and average dates of last and first frost are 18 April and 28 October, respectively.

'Hybrid 894' sunflower was planted on dates shown in

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Table 1. Planting date effect on sunflower growth, yield, quality, water use, and water use efficiency in 1980 and 1981 at Bushland, TX.

	Planting														
	Day of year		Date												
No.	1980	1981	1980	1981	Plant height	Head diam	Head wt	Seed yield	Oil conc	Linoleic acid conc	Oleic acid conc	Seed wt	Seed test wt	Water use	Water use efficiency
					m	mm	g	Mg ha^{-1}		g kg^{-1}		mg seed^{-1}	g L^{-1}	mm	kg m^{-3}
1	84	82	24 Mar.	23 Mar.	1.57	188	450	1.69	452	477	407	43.9	324	959	0.18
2	101	99	10 Apr.	9 Apr.	1.51	177	414	2.02	464	493	390	45.2	327	951	0.21
3	119	117	28 Apr.	27 Apr.	1.60	186	367	2.20	453	525	369	44.2	313	837	0.26
4	141	134	20 May	14 May	1.68	179	208	1.81	438	543	342	40.5	289	861	0.21
5	154	153	2 June	2 June	1.70	173	173	1.99	434	587	298	38.1	282	876	0.27
6	169	169	17 June	18 June	1.43	178	197	1.44	418	622	264	35.0	261	793	0.18
7	189	188	7 July	7 July	1.24	125	81	0.44	339	670	217	27.4	237	506	0.09
8	206	204	24 July	23 July	1.46	141	122	0.68	398	715	172	28.9	289	525	0.13
	LSD (0.05 level)				0.10	7	46	0.34	20	13	13	27.0	11	57	0.04

Table 1 at a rate to obtain about 64 000 plants ha^{-1}. The sunflower was planted on 1-m spaced ridges in level plots surrounded by dikes to prevent runoff of irrigation water. Average plant-available soil water content to a 1.2-m depth, measured with neutron scattering equipment, was maintained at or above the 50% level by irrigating when necessary. Water contents to a 3.0-m depth also were measured with this equipment at planting and harvest to determine changes during the growing season. Total water use was determined from net soil water extraction, precipitation, and irrigation water applied. The plots contained adequate fertilizer to a 1.2-m depth (>112 kg N ha^{-1}) for good growth or received anhydrous ammonia to raise it to that level. The soil contained adequate P and K. Separate but adjacent plots were used in different years. Plots were 25 m long and 8 m wide. Each planting was replicated four times in the experiment that had a randomized complete block design.

Before planting, trifluralin (α,α,α-trifluoro-2,6-dinitro-*N*,*N*-dipropyl-*p*-toluidine)[3] was applied at a rate of 0.11 g m^{-2} for weed control. When sunflower moth (*Homoeosoma electellum* Hulst) populations warranted control, methyl parathion [*0*,*0*-dimethyl *0*-(*p*-nitrophenyl) phosphorothioate] was applied at 0.06 g m^{-2}. Stem weevils (*Cylindrocopturus adspersus* LeConte) were controlled with a 0.11 g m^{-2} application of carbofuran (2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate).

Soil temperatures at a 5-cm depth were measured hourly with thermocouples in plots of two replications from planting until anthesis. Air temperatures were measured hourly with unshielded thermocouples at a 2-m height above the soil surface at the plot area. Solar radiation (total) was measured about 1 km from the plot area. Day lengths were obtained from Johnson and Davis (1980).

For sunflower planted on the different dates, times in days from planting to about 50% emergence, budding, anthesis, and physiological maturity were determined. These growth stages corresponded to the VE, R1, R5.5, and R9 stages identified by Schneiter and Miller (1981). On the day when most plants of a given planting reached the start of anthesis (R5 stage), about 30 plants per replication were randomly selected and marked with plastic ribbon. After 7 days and, subsequently, at 7-day intervals until physiological maturity, three heads were randomly sampled from each replication to determine head diameter and fresh weight. The heads were then partitioned into three ring-shaped zones, each corresponding to the outer, middle, or inner one-third of the head radius. Seed was obtained from each zone and dried at 100°C before determining dry matter percent, weight per seed (based on 100 seeds), oil concentration by the nuclear magnetic resonance technique (Granlund and Zimmerman, 1975), and oleic and linoleic acid concentrations of oil by the refractive index method (Goss, 1978).

Plant heights including heads were determined after anthesis. After physiological maturity, head samples were obtained from a 6-m^2 area of each plot. These samples were oven-dried at 50°C, then threshed to determine seed yield, weight per seed, and test weight. Subsamples dried at 100°C were used to determine oil concentration and oleic and linoleic concentrations of the oil by methods mentioned above.

Based on days from planting (P) to about 50% emergence (E), budding (B), anthesis (A), and physiological maturity (PM), the growing season was divided into the following periods: P-E, P-B, E-B, P-A, E-A, B-A, P-PM, E-PM, B-PM, and A-PM. For periods until A, soil temperature (ST) data were summarized for:

ST_{max}—average of daily maximums,
ST_{min}—average of daily minimums,
ST_{avg}—average of ST_{max} and ST_{min}, and
ST_{mean}—average of hourly ST ÷ 24 for each day of period.

For periods until PM, air temperature (AT) data were summarized for:

AT_{max}—average of daily maximums,
AT_{min}—average of daily minimums, and
AT_{avg}—average of AT_{max} and AT_{min}.

For these same periods, values were also obtained for ΣDL_t (summation of daylight), DL_e (average daylength), and ΣSR (summation of solar radiation). Of the ST variables, ST_{avg} usually resulted in higher simple correlations (SAS Inst., 1982) with sunflower growth development, yield, quality, and water use variables than ST_{max}, ST_{min}, or ST_{mean}. Consequently, ST_{avg} was used in multiple regression analyses (MRAs) using SAS Institute (1982) procedures. Likewise, AT_{min} resulted in higher correlations than AT_{max} or AT_{avg}, and it also was used in the MRAs.

The ST_{avg}, AT_{min}, ΣDL_t, DL_e, ΣSR, and DY (day-of-year) variables were used to establish relationships with growth development, yield, quality, and water use variables for sunflower. When the correlation coefficient for a pair of variables with simple correlation equaled or exceeded 0.70, those variables were not included in the same MRA. Although some variables for some development periods that overlapped (for example, P-B and E-B) were not highly related to each other by simple correlation, they likewise were not included in the same MRA. For MRA, the SAS STEPWISE/BACKWARD model-selection method was used to determine which independent variables had a significant effect ($P = 0.05$ for retention in model) on the dependent variable. The sunflower growth development, yield, quality, and water use data were also analyzed by the analysis of variance technique, and the LSD was calculated when differences due to planting date were significant. For this report, only the most significant relationships are presented. All relationships that were statistically significant will be presented in a companion report (Unger, 1986).

[3] This paper reports the results of research only. Mention of a pesticide does not constitute a recommendation by the USDA for use nor does it imply registration under FIFRA as amended.

RESULTS AND DISCUSSION

Duration of Growth Stages

The influence of planting time (day of year) on length of sunflower growth stages is shown in Fig. 1. Planting time had a major effect on the length of the P-E, E-B, and A-PM period, and relatively minor effect on the B-A period. Results for 1980 and 1981 were similar, except that the P-E period was shorter in 1981 for the first three plantings. Length of the P-E period steadily decreased for the first three or four plantings, then remained variable between 4 to 7 days for the later plantings. Length of most periods was highly correlated with all environmental factors (EFs) considered (data not shown). Results of MRAs involving EFs not significantly related to each other are given in Table 2.

Based on simple correlations, length of various development periods was most closely related to ΣDL_i. Other high coefficients ($P > 0.001$) resulted from most other EFs, at least for some periods.

The physical significance of ΣDL_i (time from sunrise to sunset) with respect to sunflower development is questionable. The high coefficients with this variable probably resulted from its exact nature. Other variables, except DY and DL_e, had random variability and, therefore, failed to achieve the high coefficients as the above variables. The ST_{avg}, AT_{min}, and ΣSR variables, however, are highly correlated with the ΣDL_i, DL_e, and DY variables and, thus, have a major influence on the rate of sunflower development. A direct effect of ΣDL_i may, however, also have occurred because increasing periods of daylight may provide conditions suitable for photosynthesis for a longer part of the day.

Plant Height, and Head Diameter and Weight

Average plant heights and head diameters and weights are given in Table 1. Average values are given because the differences between years were relatively small. Average values are given also for the other sunflower and the water use factors for the same reason. Plant height, head diameter, and head weight and various EFs for nonoverlapping periods were significantly

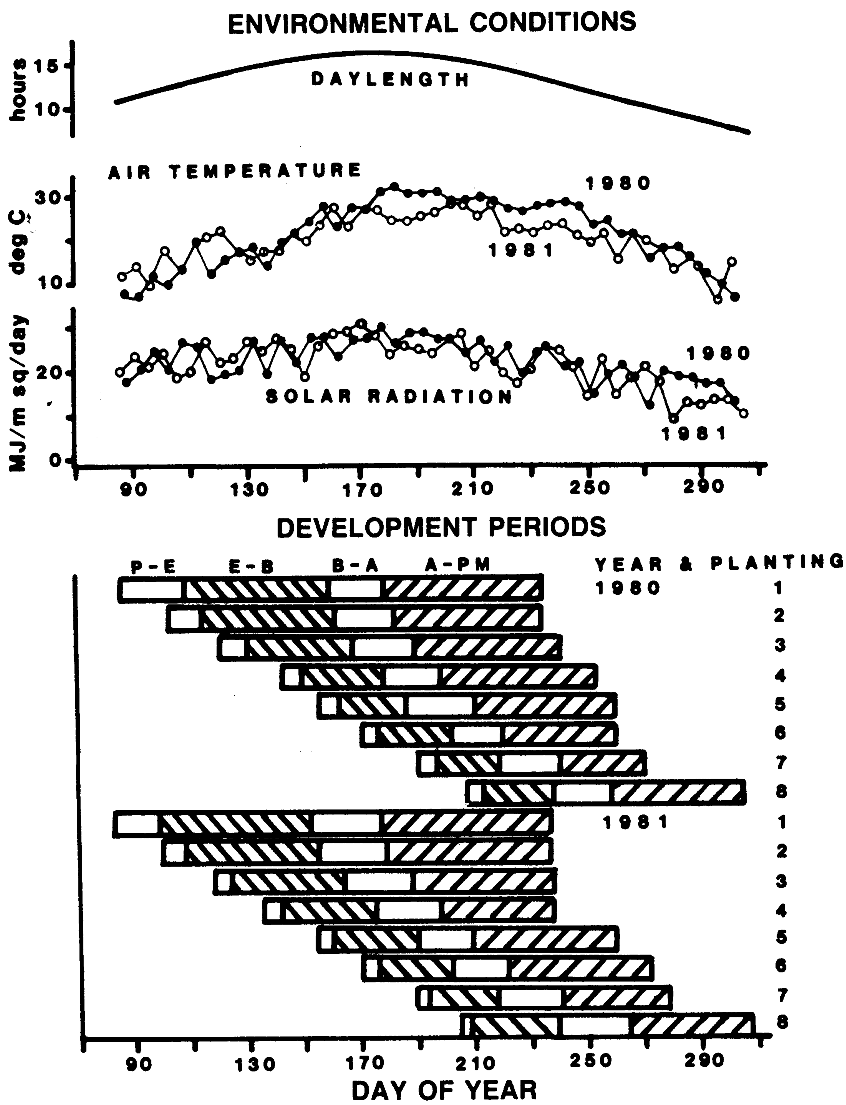

Fig. 1. Environmental conditions (day length, 5-day average air temperatures, and 5-day average solar radiation) and lengths of the development periods of sunflower planted at different times at Bushland, TX, in 1980 and 1981.

Table 2. Relationships based on multiple regression analyses between length of the sunflower development periods and various environmental factors during the development periods.

Dependent variable†	Intercept	Environmental factor‡					R^2
		ST_{avg}	AT_{min}	ΣDL_i	DL_e	ΣSR	
		equation coefficients§					
B-A	22.360	−0.099(3)	--	0.065(1)	−1.297(2)	--	0.991**
A-PM	12.540	--	−0.483(2)	0.068(1)	--	--	0.986**
B-PM	22.202	--	−0.713(2)	0.063(1)	--	--	0.976**
E-PM	96.015	--	--	0.072(1)	−6.965(2)	--	0.999**
P-PM	174.320	--	−1.334(3)	--	−10.175(2)	134.285(1)	0.995**

** Significant at the 0.01 level.
† Dependent variables are the lengths in days of the indicated sunflower development periods. Letters for periods denote: planting(P), emergence (E), budding (B), anthesis (A), and physiological maturity (PM).
‡ Environmental factors are: ST_{avg} = average soil temperature (°C), AT_{min} = minimum air temperature (°C), ΣDL_i = summation of daylight (hours), DL_e = daylength (hours), and ΣSR = summation of solar radiation (MW m^{-2}).
§ Numbers in parentheses indicate ranking of variable (1 is highest).

Table 3. Relationships based on multiple regression analyses for sunflower factors and various environmental factors during the sunflower development periods and day of year.

Dep. var. and EF†	Intercept	DY	Development period‡									R^2
			P-E	P-B	E-B	P-A	B-A	P-PM	E-PM	B-PM	A-PM	
		Equation coefficients§										
Plant height (m)												
AT_{min}	1.10	--	--	--	--	--	--	--	--	0.02	--	0.282*
DL_e	−0.53	--	--	--	--	--	0.14	--	--	--	--	0.323*
Head diam (mm)												
DY	228.14	−0.41	--	--	--	--	--	--	--	--	--	0.385*
ST_{avg}	51.94	--	--	−4.13(1)	--	--	8.93(2)	--	--	--	--	0.540**
DY and AT_{min}	117.18	−0.39(1)	--	--	--	--	5.92(2)	--	--	--	--	0.647**
AT_{min}	76.07	--	--	--	−4.62(2)	--	9.02(1)	--	--	--	--	0.723**
ΣDL_i	80.87	--	--	--	--	--	--	--	--	--	0.13	0.426**
DL_e	−291.65	--	−35.54(1)	--	67.56(2)	--	--	--	--	--	--	0.499*
ΣSR	92.60	--	--	--	--	--	--	--	--	--	259.03	0.542**
Head wt (g)												
DY	693.81	−3.06	--	--	--	--	--	--	--	--	--	0.689**
ST_{avg}	28.75	--	--	−30.65(1)	--	--	39.47(2)	--	--	--	--	0.744**
AT_{min}	214.97	--	--	--	−33.68(1)	--	30.96(2)	--	--	--	--	0.769**
DY and ΣDL_i	1255.43	−3.70(1)	--	--	--	--	−1.55(2)	--	--	--	--	0.802**
ΣDL_i	−223.75	--	1.40(1)	--	--	--	--	--	0.22(2)	--	--	0.740**
DL_e	551.84	--	−241.84(1)	--	216.21(2)	--	--	--	--	--	--	0.732**
ΣSR	−207.76	--	--	1591.25	--	--	--	--	--	--	--	0.749**
Seed yield (Mg ha^{-1})												
DY	3.20	−0.01	--	--	--	--	--	--	--	--	--	0.531**
ST_{avg}	3.96	--	--	--	−0.10	--	--	--	--	--	--	0.392**
ΣDL_i	−1.77	--	--	--	--	--	--	--	--	0.003	--	0.661**
DL_e	−10.23	--	--	--	−1.08(3)	--	3.86(1)	--	--	--	−2.04(2)	0.821**
DY and ΣSR	4.89	−0.01(1)	−13.98(2)	--	--	--	--	--	--	--	--	0.710**
ΣSR	−0.48	--	−11.51(2)	--	--	--	--	--	--	--	9.17(1)	0.815**
Total oil concentration (g kg^{-1})												
DY	533.42	−0.75	--	--	--	--	--	--	--	--	--	0.455**
ST_{avg}	616.98	--	--	--	−8.08	--	--	--	--	--	--	0.496**
AT_{min}	535.92	--	--	--	−7.13	--	--	--	--	--	--	0.404**
ΣDL_i	209.29	--	−0.32(2)	--	--	--	--	--	--	--	0.39(1)	0.906**
DL_e	262.08	--	--	--	−127.89(3)	--	301.79(1)	--	--	--	−171.56(2)	0.623**
DY and ΣSR	646.65	−1.17(1)	−935.53(2)	--	--	--	--	--	--	--	--	0.617**
ΣSR	249.91	--	−624.89(2)	--	--	--	--	--	--	475.28(1)	--	0.785**
Linoleic acid concentration (g kg^{-1})												
DY	297.05	1.95	--	--	--	--	--	--	--	--	--	0.897**
DY and ST_{avg}	506.97	1.95(1)	--	--	--	--	−8.80(2)	--	--	--	--	0.939**
ST_{avg}	737.10	--	11.28(1)	--	--	--	−17.14(2)	--	--	--	--	0.803**
DY and AT_{min}	432.73	2.03(1)	--	--	--	--	--	−9.21(2)	--	--	--	0.966**
AT_{min}	658.20	--	--	8.50(2)	--	--	--	--	--	--	−12.72(1)	0.917**
ΣDL_i	927.14	--	--	--	--	--	--	−0.22	--	--	--	0.731**
DY and DL_e	867.32	1.86(1)	--	--	--	−39.91(2)	--	--	--	--	--	0.926**
DL_e	1157.48	--	--	--	104.49(2)	--	−146.29(1)	--	--	--	--	0.941**
ΣSR	912.14	--	--	--	--	--	--	−456.23	--	--	--	0.864**

(continued on next page)

Table 3. Continued.

Dep. var. and EF†	Intercept	DY	P-E	P-B	E-B	P-A	B-A	P-PM	E-PM	B-PM	A-PM	R^2
			Development period‡									
		Equation coefficients§										
Oleic acid concentration (g kg^{-1})												
DY	583.41	−1.92	--	--	--	--	--	--	--	--	--	0.897**
DY and ST_{avg}	376.63	−1.92(1)	--	--	--	--	8.67(2)	--	--	--	--	0.939**
ST_{avg}	150.01	--	−11.11(1)	--	--	--	16.89(2)	--	--	--	--	0.805**
DY and AT_{min}	449.43	−2.00(1)	--	--	--	--	--	9.09(2)	--	--	--	0.967**
AT_{min}	197.95	--	−7.58(1)	--	--	--	--	--	--	12.17(2)	--	0.918**
AT_{min}	227.07	--	--	−8.36(2)	--	--	--	--	--	--	12.56(1)	0.918**
ΣDL_i	−36.90	--	--	--	--	--	--	0.22	--	--	--	0.730**
DY and DL_e	20.08	−1.83(1)	--	--	--	39.42(2)	--	--	--	--	--	0.926**
DL_e	−268.13	--	--	--	−102.57(2)	--	144.04(1)	--	--	--	--	0.941**
ΣSR	−22.19	--	--	--	--	--	--	449.11	--	--	--	0.864**
Seed weight (mg seed^{-1})												
DY	59.43	−0.14	--	--	--	--	--	--	--	--	--	0.503**
DY and ST_{avg}	12.47	−0.14(1)	--	--	--	--	1.97(2)	--	--	--	--	0.708**
ST_{avg}	−6.05	--	--	−1.33(2)	--	--	3.15(1)	--	--	--	--	0.625**
DY and AT_{min}	23.16	−0.14(1)	--	--	--	--	1.93(2)	--	--	--	--	0.788**
AT_{min}	7.88	--	--	--	−1.57(2)	--	3.00(1)	--	--	--	--	0.828**
ΣDL_i	11.28	--	--	--	--	--	--	0.01	--	--	--	0.408**
DL_e	−60.98	--	--	--	--	--	--	--	--	--	7.48	0.528**
ΣSR	12.92	--	--	--	--	--	--	--	--	--	85.71	0.604**
Seed test weight (g L^{-1})												
DY	373.81	−0.58	--	--	--	--	--	--	--	--	--	0.558**
ST_{avg}	422.52	--	--	−5.66	--	--	--	--	--	--	--	0.649**
AT_{min}	347.41	--	--	−9.06(1)	--	--	8.81(3)	--	--	--	−4.99(2)	0.792**
ΣDL_i	156.76	--	--	--	--	--	--	--	--	--	0.20	0.744**
ΣDL_i	157.52	--	--	--	--	--	--	0.08	--	--	--	0.744**
DL_e	814.21	--	−37.90	--	--	--	--	--	--	--	--	0.640**
ΣSR	173.14	--	--	--	--	--	--	--	173.52	--	--	0.711**
Water use (mm)												
DY	1309.24	−3.60	--	--	--	--	--	--	--	--	--	0.530**
ST_{avg}	1262.34	--	−21.39	--	--	--	--	--	--	--	--	0.496**
DY and AT_{min}	732.92	−3.49(1)	--	--	--	--	30.76(2)	--	--	--	--	0.660**
AT_{min}	384.96	--	−23.12(1)	--	--	--	38.64(2)	--	--	--	--	0.711**
ΣDL_i	−182.75	--	--	--	--	--	--	--	--	1.03	--	0.590**
DL_e	−2749.05	--	--	--	--	--	252.44	--	--	--	--	0.577**
ΣSR	141.71	--	--	--	--	--	--	--	--	--	2221.71	0.732**

*,** Significant at the 0.05 and 0.01 level, respectively.

† Dependent variables (Dep. var.) and environmental factors (EF). The dependent variables are the indicated sunflower factors (plant height, head diam, etc.). The independent variables are the environmental factors listed under the dependent variables, with each analysis based on a DY value and/or values for another environmental factor for the development periods for which an equation coefficient is given. Environmental factors are: DY = day of year, ST_{avg} = average soil temperature (°C), AT_{min} = minimum air temperature (°C), ΣDL_i = summation of daylight (hours), DL_e = daylength (hours), and ΣSR = summation of solar radiation (MW m^{-2}).

‡ Letters for periods denote: planting (P), emergence (E), budding (B), anthesis (A), and physiological maturity (PM).

§ Numbers in parentheses indicate ranking of variable (1 is highest).

related by simple correlations (data not shown). Besides the significant correlations, plant height was significantly related to DL_e during the B-A period and to AT_{min} during the B-PM period (Table 3). The relatively low correlations between plant height and the EFs were not entirely unexpected because previous research (Unger, 1982, 1983) showed that the availability of water from emergence to anthesis greatly influenced plant height when other factors were equal. In this study, soil water contents were maintained at adequate levels for good growth throughout the season.

Head diameter at PM was significantly related to numerous variables or combinations of variables, but only the relationships with the highest R^2 values are shown (Table 3). The highest R^2 value (0.723, P = 0.01) resulted from the MRA involving AT_{min} during E-B and B-A periods. The R^2 values were generally low for MRAs involving DY, ΣDL_i, DL_e, and ΣSR.

Head weight at PM was significantly related to numerous variables or combinations of variables (Table 3), with the highest R^2 value (0.802, P = 0.01) resulting from a MRA involving DY and ΣDL_i for the B-A period. Not unexpected was a high simple correlation (0.771) between head weight and head diameter.

The close relationship between head diameter and AT_{min} during the E-B and B-A periods indicates that favorable plant growth conditions during vegetative stages (emergence to anthesis) are conducive to plants with large diameter heads. For head weight, favorable conditions for vegetative development were still important, but also important (with lower R^2 values) were AT_{min}, ΣDL_i, DL_e, and ΣSR variables extending to physiological maturity (PM), which included the period of seed development and, therefore, increases in head weight (relationships not shown).

Yield

For yields, the highest simple correlation (0.835, P = 0.001) with an EF resulted from DL_e for the B-A period. Other EFs were also significantly related to yield by simple correlation (data not shown).

Planting date (DY) alone, DY in combination with ΣSR for the P-E period, ST_{avg}, ΣDL_i, DL_e, and ΣSR variables were significantly related to yield (Table 3). The highest R^2 value (0.821) resulted from DL_e variables for E-B, B-A, and A-PM periods.

Seed yields resulting from the first planting averaged significantly lower than those for the second and third plantings; were similar to those for the fourth, fifth, and sixth planting; and were higher than those for the last two plantings (Table 1). Except for the increase after the first planting, the general decline with subsequent plantings was similar to trends for the southern Great Plains reported by Unger (1980). In this study, planting date (DY variable) accounted for 53% of the variation in yield (Table 3). Other variables or combinations of variables accounted for 39 to 82% of the yield variation. The generally closer relationships between yields and DY and DL_e variables than between yields and ST_{avg}, AT_{min}, and ΣSR variables are attributed to the more exact nature of the former variables. The latter variables were, however, closely related to the former variables and undoubtedly had a major effect on seed yields.

Seed yield was significantly related to variables covering all development periods, but generally was most closely related (simple correlations and MRAs) to variables that extended to PM. These results substantiate earlier findings that showed the importance of adequate water during early growth stages and during seed filling for obtaining high yields of sunflower in the southern Great Plains (Unger, 1982, 1983).

Oil Concentration, and Linoleic and Oleic Acid Concentrations of the Oil

Except for some minor variation, oil concentration in seed generally declined from the first to the last planting. Also, linoleic and oleic acid concentrations of the oil consistently increased and decreased, respectively, from the first to the last planting (Table 1). These results are similar to those previously reported (Unger, 1980) for the southern Great Plains.

Numerous EFs were significantly correlated with oil concentration in seed, with almost identical high simple correlations (0.899 and 0.892) occurring between oil concentration and length of or ΣDL_i for the A-PM period. Based on R^2 values for MRAs involving oil concentration and various EFs, oil concentration was most closely related to ΣDL_i for the P-E and A-PM period, with $R^2 = 0.906$, but significant R^2 values also resulted from MRAs involving other variables (Table 3). When used in a MRA, variables for the B-A, B-PM, or A-PM period generally resulted in the highest ranking with respect to their influence on the relationships. This was expected because oil is produced during these latter developmental stages.

The highest simple correlation (0.947 for both acids) involving linoleic and oleic acid concentrations of the oil resulted from the DY variable. Progressively later planting dates resulted in sunflower seed development and maturation during periods of progressively lower air temperatures, which have resulted in increasing and decreasing concentrations of linoleic and oleic acid in sunflower oil, respectively (Canvin, 1965; Harris et al., 1978; Johnson and Jellum, 1972; Keefer et al., 1976; Unger, 1980). The MRA relationships between linoleic or oleic acid concentration of oil and the EFs were similar, except that the coefficients for the two acids were opposite in sign because of the inverse relationships between linoleic and oleic acid concentrations.

The R^2 values for MRAs involving linoleic acid concentration and various EFs ranged from 0.731 for the relationships involving ΣDL_i for the P-PM period to 0.966 for the relationships involving DY and AT_{min} for the P-PM period. Values for oleic acid were similar. For the P-PM period, AT_{min} had a ranking of two and had much less influence on the relationship than DY, which alone accounted for almost 90% of the variability in acid concentrations. The close relationship with DY was not unexpected because DY influences the prevailing temperature during the period of oil formation, as mentioned above.

Seed Weight and Seed Test Weight

There were significant simple correlations between seed weight (mg seed^{-1}) or seed test weight (g L^{-1}) and most EFs evaluated. For seed weight, the highest R^2 value (0.828) was obtained for the MRA involving AT_{min} for the E-B and B-A periods (Table 3). Generally low R^2 values were obtained for MRAs involving DY, ΣDL_i, and DL_e variables. For seed test weight, the highest R^2 value was 0.792 for AT_{min} for the P-B, B-A, and A-PM periods. Other R^2 values for seed test weight were generally higher than those for seed weight.

Seed weight was most closely related to AT_{min} for the E-B and B-A periods, which was also the case for head diameter. This indicates the importance of large heads for obtaining heavy seeds. The coefficient for the simple correlation between head diameter and seed weight was 0.771 ($P > 0.001$). Seed weight, however, also depends on well-developed seed of which test weight is an indicator. For the simple correlation between seed weight and seed test weight, the coefficient was 0.578 ($P = 0.05$). Simple correlations also showed that test weight was closely related ($P > 0.001$) to length, ΣDL_i, and ΣSR for the A-PM period. These conditions provided an adequate time of favorable conditions for the development of high test weight seed.

Water Use and Use Efficiency

Total water use during the growing season (net soil water depletion, precipitation, and irrigation) was significantly related by simple correlation to most factors considered. The highest correlation coefficient (0.855) was for the relationship between water use and ΣSR for the A-PM period.

The highest R^2 value obtained for MRAs involving water use and various EFs was 0.732 for ΣSR for the A-PM periods (Table 3). Another MRA with $R^2 >$ 0.700 involved AT_{min} for the P-E and B-A periods.

Total water use was negatively correlated with DY for planting. Early plantings (low DY value) resulted in slower plant development (Fig. 1) and, consequently, longer growing seasons that resulted in greater total water use, and lower use efficiency, even though part of the growing season for early planted sunflower occurred during a time of year (April–May) when potential evapotranspiration (ET) was lower than for later-planted sunflower that develop during periods of higher ET. The longer growing season overshadowed the effects of higher potential ET, thus the greater total water use and lower use efficiency for early planted sunflower. The effect of the extended growing season on total water use was further substantiated by the positive coefficients for simple correlations with length of the different periods. Most coefficients were significant at $P = 0.05$. Other variables also resulted in significant coefficients, but they (for example, ΣDL_i and ΣSR) were related to length of the different periods. Lower water use efficiencies for late plantings resulted from the low seed yields (Table 1).

Head and Seed Development from Anthesis to Physiological Maturity

Results of the head and seed samplings at 7-day intervals, starting 7 days after anthesis, are presented in Table 4. Although seed samples were obtained at three head positions (outer, mid, and inner one-third of head radius), only average values for the head are presented. At early samplings for a given planting, seed at the outer position had the highest dry matter concentration, weight, total oil, and linoleic acid concentration of oil and lowest oleic acid concentration of oil. At later samplings, the differences usually became slight or the trends even reversed, especially for total oil concentrations. These trends were similar to those reported by Unger and Thompson (1982).

Relationships among changes in values for successive samplings for head and seed factors and sampling day (DY), week (after first sampling), and average AT_{max}, AT_{min}, AT_{avg}, SR, and DL_e variables for the sampling interval were established by simple correlation and MRAs. As for previous MRAs, only those EFs not related to each other by high ($r > 0.700$) simple correlation were used in a common MRA.

Head diameter was not significantly related to any EF by simple correlation, and head weight was only related to DY. Dry matter of seed from different head areas usually was not significantly related to any EF, but average seed dry matter was significantly related to all EFs, except DY and AT_{max}. In contrast, weight of seeds from different head areas was significantly related to all EFs, except week of sampling and DL_e. Average seed weight was related to all EFs, except AT_{max} and AT_{avg}. Most oil concentration and oleic and linoleic acid concentration variables were not significantly related to the EFs. Exceptions were the sampling day (DY) effect on oil concentration of seed from the mid and inner sections of the head; week of sampling effect on average oil concentration; and week of sampling, SR, and DL_e effects on average oleic acid concentration.

The generally low simple correlations between changes in head and seed factors for successive samplings and the EFs indicate that the changes are, in most cases, not greatly affected by a single environmental factor, but by a combination of environmental factors. This was substantiated by MRAs involving various combinations of the EFs (Table 5).

The highest R^2 values were obtained for relationships involving average seed dry matter concentration as the dependent variable. For these relationships, DL_e resulted in the highest ranking when other EFs were involved. The close relationship between changes in dry matter concentration and DL_e is attributed to the rapid initial dry matter accumulation (changes between early samplings) when average DL_e was longer than between later samplings when changes in dry matter accumulation became small. The DL_e factor per se may have had little physical influence on dry matter changes for seed from plants of a given planting. For the entire season, however, DL_e undoubtedly had at least an indirect influence on dry matter changes through its influence on other variables (AT and SR). These latter variables were more variable than the DL_e variable and, therefore, were not as closely related to the dry matter variable.

Other relatively high R^2 values were obtained for MRAs involving average seed weight and oil concentration. For these relationships, DL_e and week of sampling usually resulted in rankings of one or two. Week of sampling, as for DL_e, was less variable than the AT and SR variables and, therefore, resulted in a generally high ranking.

SUMMARY AND CONCLUSIONS

Sunflower was planted at Bushland, TX, from late March to late July in 1980 and 1981, and was adequately irrigated so that water deficiency did not limit growth. Relationships among sunflower growth, yield, quality, and water use variables and environmental variables [time of planting (day of year—DY), average soil temperature (ST_{avg}), minimum air temperature (AT_{min}), summation of solar radiation (ΣSR), summation of daylight (ΣDL_i), and average daylength (DL_e)] were established by simple correlation and multiple linear regression analyses.

Time of planting significantly affected plant height, head diameter and weight, seed yield, total oil concentration, linoleic and oleic acid concentrations of the oil, seed weight and test weight, and total water use. In addition, many of the relationships among sunflower and environmental variables were statistically significant. The more-precisely determined environmental variables (DY, ΣDL_i, DL_e, and week of sampling) generally resulted in higher correlation coefficients than the ST_{avg}, AT_{min}, or ΣSR variables. Although DY, ΣDL_i, and DL_e per se may have limited, direct physical significance with respect to sunflower growth, development, yield, and quality, they have a large effect on the temperature and radiation variables, as was indicated by results of simple correlations involving these variables. The temperature and radiation variables undoubtedly have greater physical significance.

Based on this study, sunflower in the Texas High Plains should be planted from about mid-April to early June to use water efficiently and to obtain favorable yields of seed having a high oil concentration.

Table 4. Sunflower head, seed, and oil factors as influenced by planting date and time of sampling. Values for seed and oil factors are averages for samples from three head areas.

Factor	Sampling no.†	Planting no.‡							
		1	2	3	4	5	6	7	8
Head diam (mm)	1	214	199	190	196	190	189	146	139
	2	204	184	192	182	185	187	146	133
	3	198	176	199	184	171	166	129	129
	4	200	188	180	178	179	176	106	130
	5	180	184	174	179	175	192	106	125
Head weight (g)	1	445	378	358	424	385	367	259	230
	2	461	380	439	387	422	416	264	239
	3	481	390	516	399	331	304	122	225
	4	527	468	439	342	283	251	34	164
	5	450	441	384	278	198	185	34	97
Dry matter conc (g kg^{-1})	1	158	153	164	177	165	146	160	158
	2	273	286	281	312	265	239	239	227
	3	401	437	424	453	418	421	407	360
	4	539	542	572	563	564	552	585	486
	5	664	681	659	778	775	650	585	613
Seed wt (mg)	1	11.3	10.5	11.7	14.1	12.6	9.5	9.4	8.2
	2	21.7	21.0	22.5	23.0	22.2	18.1	13.9	13.7
	3	30.6	28.7	32.1	31.4	27.3	24.4	17.1	19.9
	4	38.9	38.7	38.6	37.8	33.0	30.0	18.8	24.3
	5	42.2	43.1	42.2	42.1	36.3	31.8	18.8	23.8
Oil conc (g kg^{-1})	1	37	51	49	59	75	36	43	48
	2	199	226	236	273	282	219	234	178
	3	370	413	389	398	405	413	265	341
	4	427	460	459	449	423	418	364	389
	5	467	478	467	445	428	403	364	366
Oleic acid conc (g kg^{-1})	3	554	508	504	436	344	351	257	284
	4	478	465	422	347	276	238	209	195
	5	426	436	360	326	269	236	211	163
Linoleic acid conc (g kg^{-1})	3	337	373	377	446	540	532	629	602
	4	404	418	460	537	609	647	676	692
	5	456	446	523	558	615	674	676	724

† Numbers correspond to weeks (based on 7 days each) after 50% anthesis.
‡ Respective planting dates in 1980 and 1981 that correspond to the planting numbers are: 1, 24 and 23 Mar.; 2, 10 and 9 Apr.; 3, 28 and 27 Apr.; 4, 20 and 14 May; 5, 2 and 2 June; 6, 17 and 18 June; 7, 7 and 7 July; and 8, 24 and 23 July.

Table 5. Relationships based on multiple regression analyses among changes in sunflower head, seed, and oil factors and sampling time (DY), sampling week (week after anthesis), air temperature (AT_{min}), solar radiation (SR), and daylength (DL_e). Average temperature, radiation, and daylength values for the sampling interval were used in the analyses.

Dep. var.†	Intercept	Independent variables					R^2‡
		DY	Week	AT_{min}	SR	DL_e	
		equation coefficients‡					
Head diam (mm)	−3.766	--	2.713(2)	--	--	−0.482(1)	0.122*
Head wt (g)	185.610	−0.824(1)	−3.941(2)	--	--	--	0.159**
DM conc (g kg^{-1})—A	−0.180	0.001(3)	−0.005(2)	--	0.025(1)	--	0.144*
DM conc (g kg^{-1})—B	0.018	0.001(2)	--	--	0.010(1)	--	0.101*
DM conc (g kg^{-1})—B	0.076	--	--	--	0.008	--	0.093*
DM conc (g kg^{-1})—C	0.047	--	0.011(2)	--	0.012(3)	−0.002(1)	0.127*
DM conc (g kg^{-1})—avg	−0.668	0.001(2)	--	--	0.022(3)	0.024(1)	0.996**
DM conc (g kg^{-1})—avg	−0.158	--	--	−0.002(2)	--	0.025(1)	0.996**
Seed wt (g)—A	16.678	−0.036(3)	−1.822(1)	--	--	0.283(2)	0.473**
Seed wt (g)—B	18.344	−0.048(3)	−0.884(1)	--	--	0.137(2)	0.387**
Seed wt (g)—C	20.882	−0.064	--	--	--	--	0.266**
Seed wt (g)—avg	15.418	−0.043(3)	−0.985(2)	--	--	0.292(1)	0.723**
Oil conc (g kg^{-1})—A	123.031	--	−60.362(1)	--	--	9.151(2)	0.782**
Oil conc (g kg^{-1})—B	126.740	--	−56.756(1)	--	--	8.677(2)	0.761**
Oil conc (g kg^{-1})—C	120.115	--	−45.258(1)	--	--	6.814(2)	0.549**
Oil conc (g kg^{-1})—avg	133.215	--	−53.153(1)	--	--	7.392(2)	0.769**
OA conc (g kg^{-1})—A	−166.555	--	33.340(2)	--	11.905(3)	−5.448(1)	0.443**
OA conc (g kg^{-1})—B	−113.950	--	36.234(1)	--	--	−5.199(2)	0.428**
OA conc (g kg^{-1})—C	−112.548	--	35.164(1)	--	--	−5.199(2)	0.379**
OA conc (g kg^{-1})—avg	−114.275	--	33.727(1)	--	--	−4.434(2)	0.544**
LA conc (g kg^{-1})—A	175.663	--	−35.007(2)	--	−13.511(3)	5.767(1)	0.422**
LA conc (g kg^{-1})—B	114.933	--	−37.246(1)	--	--	5.352(2)	0.412**
LA conc (g kg^{-1})—C	113.690	--	−36.262(1)	--	--	5.370(2)	0.362**
LA conc (g kg^{-1})—avg	110.194	--	−34.819(1)	--	--	4.963(2)	0.413**

*,** Significant at the 0.05 and 0.01 level, respectively.
† Dependent variables. The letters A, B, and C after the variables indicate the outer, mid, and inner one-third sections of the head, based on the radius of the head. Abbreviations used are DM (dry matter), OA (oleic acid), and LA (linoleic acid).
‡ Numbers in parentheses indicate ranking of the variables.

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